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LONG-RANGE PLANNING OF THE ELECTRIC POWER SYSTEM

REPORT NO • 556 SP

FEBRUARY • 1 • 1974

ontario hydro  The logo for Ontario Hydro, featuring a stylized 'OH' inside a square with a circle at the top.



memorandum to MR. H.A. SMITH
Chief Engineer

date February 1, 1974

location or dept. H-1610

file 202.03N

subject

Long-Range Planning
of the Electric Power System

Attached is a copy of System Planning Division Report 556SP dated February 1, 1974 and entitled "Long-Range Planning of the Electric Power System". The report discusses the factors which must be taken into account in the long-range planning process, the constraints which must be observed, and the options and trade-offs available. It presents several alternative plans for long-range development of the generation and bulk power transmission.

The report considers a range of possible rates of load growth between 4% and 10% per annum, resulting in a 1993 load demand ranging from 33,000 MW to 75,000 MW. After reviewing the types of generation likely to be available in future, the report concludes that for present planning purposes, we should assume that most new generation in the next 20 years will come from large central stations, nuclear or fossil fired, much like stations such as Bruce and Nanticoke.

The report shows that, for all the alternative generation programs considered, new generating station sites will be necessary, and that three sites in the East System and one in the West System, beyond those already owned, may be required for development by 1985.

The report also concludes that 500 kV is an adequate voltage level for Ontario until beyond 1990. The circuits required in the near future will have to be overhead on the basis of lead time, cost and reliability. In later years, as the technology develops further, 500 kV underground circuits will be required in certain areas. Also, considerable effort will continue to be expended in future to minimize the effect of overhead circuits on land use, aesthetics, and the environment.

MR. H.A. SMITH

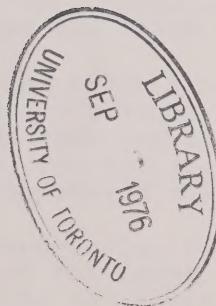
February 1, 1974

The Commission considered a draft of this report on January 9, 1974, and authorized its issue in final form to Ontario Hydro personnel, to Ontario Government Ministries, and to public hearings and meetings as required for back-up material.

The tentative long-range plans outlined in Report 556SP will be reviewed periodically.

INFORMATION COPY
ORIGINAL SIGNED BY

H.P. Smith
Director of System Planning



ONTARIO HYDRO
System Planning Division

A REPORT
ON
LONG-RANGE PLANNING
OF THE
ELECTRIC POWER SYSTEM

Report No. 556 SP

Date: February 1, 1974



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Long-Range Planning of the
Electric Power System

1. Introduction

Ontario Hydro is one of the world's major electric power utilities. In 1972, the assets equalled \$5 1/2 billion, revenues equalled \$700 million, capital expenditures equalled \$560 million, and the Ontario Peak Load exceeded 12,700 megawatts. The demand is expected to double in the next ten years and may redouble during the ten years following.

Our customers have come to take reliable electric service for granted, but the continuance of reliable service through a period of rapid system expansion requires considerable planning effort. This report describes the complexity of the electric utility business, the planning goals which must be achieved, the technical, environmental, and social constraints which must be taken into account, and the compromises and trade-offs which must be made. Considering these factors it outlines alternative plans for expansion of the generation and bulk power transmission network for the next twenty years.

This report is intended as an overview of the factors involved in planning the expansion of the electric power system. To preserve readability it has been necessary to omit detailed explanations of many of the factors.

2. Factors in Planning System Expansion

2.1 Abundant Supply

Ontario Hydro has considered its role to be the provision of generation and transmission facilities to supply the electric power demands of the people of the province. An abundant, low cost supply of electricity has resulted in large social benefits in terms of convenience, comfort, and productivity, but at the social cost of some encroachment on the natural environment. Recently, some people have strongly opposed further encroachment, and have advocated the limiting of load growth. On the other hand, in an effort to limit their own contribution to pollution, other people have switched from fossil fuels to electricity, producing a trend to increased load growth. Additional load growth will occur if

people try to compensate for the oil shortage by switching to electricity.

Long-range planning must consider the balance of social benefits and social costs, and must also consider the effect on load growth of changes in public attitudes towards social factors.

2.2 Reliable Supply

Our customers expect a high level of reliability in electricity supply. Even a short interruption can cause financial loss by shutting down an industrial process or personal inconvenience by stalling elevators and subway trains. A long interruption can cause traffic chaos by disabling traffic lights and gasoline pumps, and can cause inconvenience at home by disabling electric freezers and house heating systems (whether "electric", oil or gas).

The level of reliability required in the supply of electricity is considerably higher than the reliability of the individual generators and transmission lines which are essential parts of the supply system. It is part of the planning function to determine the extent of reserve required in these major supply facilities to provide adequate reliability.

Reliability is treated more fully in Appendix I.

2.3 Reasonable Cost

Ontario Hydro's objective has been to supply all electric demands safely, reliably, within environmental standards, and at the lowest feasible cost consistent with financial stability. Recent public concern over quality of the environment is resulting in higher environmental standards which are increasing Ontario Hydro's costs. As a matter of policy, it will be necessary to establish a system of trade-offs in order to strike a balance among:

1. Increasing capital expenditures to meet increasing environmental standards.
2. Accepting lower environmental standards to conserve capital.

3. Reducing reliability or curtailing load growth to permit meeting the desired environmental standards within limited capital requirements.

Since there is no basis at present on which to make these trade-offs, long-range planning must consider the effects of a range of conditions and try to maintain flexibility to meet the load demand under whatever trade-offs are decided upon.

2.4 Minimum Effect on Environment

The electric utility produces some adverse effects on the air, water and visual environments. However, we are not the only offender in this regard. All industrial development has been achieved at the expense of some intrusion on the existing environment. The increasing pace of development over the past few years has given rise to the fear that irreversible damage will be done.

A long-range plan must preserve flexibility to construct facilities which will do an adequate job with minimum effect on the environment under existing technology, while keeping a way open to take advantage of any technological breakthroughs which might occur.

2.5 Lead Times

A difficult problem in planning is to allow sufficient lead time for public participation, property acquisition, design, ordering of materials, construction, and testing, and still get new facilities into service at the time they are required. In many cases final planning decisions must be made 5 to 10 years before the required in-service date. It is difficult to obtain public acceptance of the following facts:

- (i) A supply system may be quite adequate today but, with inexorable load growth, there will be a gradual deterioration in reliability unless new facilities are added. Because of our long lead times, a delay in authorizing new construction will have no immediate effect on reliability but will reduce the reliability several years in the future.

(iii) Once a deterioration in reliability has occurred, the long lead times dictate that there will be several years of poor reliability before the matter can be corrected.

2.6 Conflicting Requirements

It is not usually possible to optimize all the above factors at the same time, so trade-offs are necessary. The example of choice of fuel for a generating station will indicate some of the trade-offs which must be considered. This choice must be made at the earliest stage, before the plant is committed for construction. If nuclear fuel is chosen, there is minimum effect on air quality, and visual effect is relatively small, but capital requirements are high and the quantity of cooling water is greater than for a fossil plant. Choice of a fossil fuel will favour low capital and lower effect on water at the expense of considerable difficulty in maintaining acceptable air quality. Among fossil fuels, gas is cleanest, but also is expensive and scarce. Coal is most abundant but the common type of coal creates difficulties in maintaining acceptable levels of sulphur dioxide emissions and low-sulphur coal is in short supply. The long-term availability of oil is in doubt. The choice among fossil fuels must take into account not only the cost and environmental effects at the new plant being planned, but also the diversity among coal, oil and gas over all the plants on the system, so as to reduce the impact of temporary shortages of any one fuel.

Trade-offs must be made within limits of four main areas of endeavour :

1. Technical - we must operate within the natural laws of physics and chemistry, and at the existing state of engineering technology in applying these laws.
2. Ecological - we must consider the effects on the balance of nature, and limit adverse effects.
3. Social - at the point of use, electricity is the cleanest, most versatile, and most convenient form of energy. This advantage is obtained at the cost of high capital requirements and pollution at the

source of generation. Society puts a varying and not always consistent value on these factors. We must operate within the current value-system, but must remain alert for changes.

4. Group Action - The demands of special interest groups are increasingly being made known. Our decision on technical, ecological and social matters must be defensible before these groups.

2.7 Need for Judgement

Because the electric utility business is highly technical, many people believe that a computer can provide answers to all problems. This is not the case. While the computer easily surpasses human ability in speed and accuracy of manipulating data, its ability to come up with solutions is only as good as its programmer. For many problems, the criteria may change rapidly, and factors other than those which can be resolved by computation are involved.

In the past it was acceptable for certain major decisions to be based on "judgement", which is the accumulated experience and intuition of the decision maker combined together in an indefinable way. However, in the future such decisions will have to be documented so that they can be reviewed by critics who do not have the experience of the decision maker. Hence, future decisions may tend towards those which can be documented and defended rather than those which seem the best to the decision maker.

3. The Meaning of a Long-Range Plan

Effective planning must consider tentative plans for distant needs while at the same time completing arrangements for the immediate future. Long-range planning is necessary to assure orderly and timely development of appropriate facilities.

The long-range plan developed by an electric utility is different from a long-range plan for land use or regional development issued by a government. The government plan is a statement of intent, with the implication that it will be backed up by legislation which will ensure that the plan comes to fruition. A utility plan, on the other hand is only a statement of

what might happen in the future if certain other things, over which the utility has no control, come to pass. The utility plan can only say that if the load growth is in a certain range, and if certain technological and social changes take place, it is most likely that a future power supply system of the type shown in the plan will be adequate for supply of electric power in the area.

A utility long-range plan must therefore, be very tentative, flexible, and general in content. To achieve adequate flexibility it is necessary to formulate a series of alternative long-range plans. Also a long-range plan must provide a context within which short-range plans can be developed. That is, short-range plans should be compared and selected according to their relative capability to be useful within the broad spectrum of the long-range plan.

As long as the tentative nature of the utility's long-range plan is recognized, the plan can be of value to governments, action groups, and members of the public, in providing them with a context within which to evaluate short-range plans announced by the utility.

4. Load Growth

Over the past half century, Ontario Hydro's load has grown in a climate of plenty. There has been space for the growing population, the economy has grown to support the population, supplies of raw materials and capital funds have been adequate, and physical environmental constraints have not prevented us from supplying the electric demands. In this climate, our load over the past fifty years has grown at an average compound rate of 6.8% per annum.

The load is by no means uniformly distributed over the province. At present, the distribution is approximately as follows:

Oshawa-Toronto-Hamilton-Niagara	45%
Rest of Southern Ontario	40%
Northeastern Ontario	10%
Northwestern Ontario	5%

We believe that programs for new generation and bulk power transmission in the period up to 1982 should be based on a continuation of an overall provincial load growth rate of 6.8% to 7%. The rate will not be the same for each area of the province, and

it appears likely that the more heavily industrialized southern parts will grow somewhat faster than other parts of the province.

In the longer term, there are two factors which will have conflicting effects on load growth:

- the emphasis on reducing air pollution may tend to cause users of fossil fuels to convert to electricity, thus increasing load growth. An oil shortage may have a similar effect
- impending shortages of fossil fuels, metals, and living space may force drastic changes in social conditions and reduce electric load growth

The uncertainty in the prediction of load growth over the next 20 years complicates the problem of producing a long-range plan. It is therefore, necessary to adopt a basic middle-of-the-road prediction at 7% per annum and then to consider the effect of higher and lower load growths.

For the East System which lies roughly east of Wawa the following alternatives have been arbitrarily assumed as shown in Figure 1:

- (i) Base continued growth at 7% per annum
- (ii) High growth rate rising to 10% per annum by 1982 and continuing at that level
- (iii) Low growth rate falling to 4% per annum by 1982 and continuing at that level

5. Sources of Generation

5.1 General

Electric energy does not occur naturally, but must be manufactured from energy in other forms and used instantly. Each user could produce his own electricity by purchasing oil, natural gas, hydrogen, etc and converting it to electricity on his own premises. Because of the cost and complexity of the electric generating equipment, this do-it-yourself method has never been used on a wide scale. Instead, electric utilities have been formed to convert energy into electricity and distribute it to users in the electric form. It has been convenient and economic for these

utilities to produce electricity in large central generating stations rather than in a myriad of small stations scattered throughout the service area. The various types of generation used by the utilities, and by Ontario Hydro in particular, are described briefly in this section.

5.2 Hydro-Electric Stations

The Ontario Hydro system was almost entirely hydro-electric from its inception until 1951 when the first major thermal unit was placed in service. Now most major hydro-electric sites in Ontario have been developed to their full energy capability. There remain some smaller sites which can be developed to provide energy, and the possibility of adding peaking units at some existing sites.

There is the possibility of developing additional energy on several rivers of northern Ontario, such as the Albany but the cost is high. Also at high cost, lesser developments could be made on some of the minor rivers.

It therefore appears unlikely that new hydro-electric developments will provide a significant part of our future developments.

Pumped storage plants provide peak capacity, but no energy. The only existing pumped storage plant on our system is at Beck GS, but there are several other potential sites such as Delphi Point. These sites are unlikely to be developed until after a substantial amount of nuclear capacity has been developed, that is until the late 1980's.

5.3 Fossil and Nuclear Plants

These plants convert the chemical energy of fossil fuel or the nuclear energy of uranium first into heat for boiling water, then into mechanical energy in a steam turbine, and finally into electric energy in a generator. In recent years, large fossil plants such as Lambton GS have accounted for most new thermal generation on the Ontario Hydro system, but increasingly in future large nuclear plants such as Pickering GS will be built.

In making an economic comparison of fossil vs nuclear, it is necessary to consider each plant separately. Recent and expected future rises in

the cost of fossil fuels tend to make nuclear plants more economic than fossil plants. In operating characteristics, fossil and nuclear plants differ considerably but tend to complement each other. We expect to build both types during the next few years, with nuclear accounting for somewhat more than half.

Nuclear plants have the following advantages over fossil plants:

1. Lower fuel cost for base-load operation.
2. Expected greater stability in long-term fuel cost.
3. Negligible contribution to air pollution.
4. Better assurance of long-term fuel availability.
5. Better adaptability to aesthetic designs.

Fossil plants have the following advantages:

1. Lower capital cost.
2. Greater flexibility for intermediate and peak load operation.
3. Smaller heat rejection to cooling water.
4. Shorter construction lead time.

The technology of fossil plants is mature, and evolutionary changes are likely to come about slowly. On the other hand, the technology of nuclear plants is changing rapidly. In addition to the pressurized heavy water reactor (CANDU) being built in Ontario, there are several other types being built elsewhere, such as pressurized light water, boiling light water, gas cooled, etc. Much attention is now being given to the development of a "breeder reactor" which in addition to providing heat energy also converts fertile material into fissile nuclear fuel. Work is also going on to develop a fusion reactor, but this is unlikely to become commercially viable within twenty years.

The decision of fossil versus nuclear for a new generating station is one of the most complex problems which the decision makers in an electric

utility must face. The decision maker must take into account all the factors in which the two types differ, and must predict how the two types would fit into the power system envisaged for several years hence, and for the following 30 years. Frequently there is the additional complication that the choice must be made between a nuclear plant of the most economical size on one site and a fossil plant of a different economical size on a different site, thus introducing the social and technical aspects of different transmission networks into the study. Because of the high capital cost of a generating station, a heavy financial penalty can result from any but the optimum decision.

5.4 Size of Major Units and Plants

In the interest of reducing capital and operating costs, and increasing efficiency, there has been a trend to larger and larger unit sizes in conventional fossil and nuclear plants. At present the Tennessee Valley Authority 1250 MW fossil unit is the largest in the world, and several 1050 MW nuclear units are scheduled for service in the U.S.A., within a year. Manufacturers and consultants are predicting that a 2000 MW unit will be placed in service between 1980 and 1990. On our system, the largest existing units are the 500 MW units at Lambton, Nanticoke, and Pickering. Units of 750 MW size are scheduled for Bruce in 1976.

The selection of a unit size for a new plant depends on a combination of technical and economic factors, but ultimately requires a large measure of judgement. The following are some of the factors which must be considered:

- Capital and operating cost of the unit
- Effect of a new large size unit on reserve requirements
- Suitability of the site, foundation conditions, transportation, etc.
- Capability of the transmission system
- Reliability of large units
- Possibility of problems with large prototype units

As with unit sizes, there has also been a trend to larger plant sizes. Our largest existing plant is Lakeview at 2400 MW, but Nanticoke is scheduled to reach 4000 MW in 1977. Even larger plants are likely to be built in later years as the load grows. The maximum size for any plant is governed by a number of factors some related to security and some related to the technical problems of handling the quantities of fuel, combustion products, and cooling water involved. There are also factors such as land use and aesthetics. Security is the most difficult aspect to judge, since there is no rigorous method of analyzing it. The contingencies which can cause loss of a whole plant are very improbable, but the consequences of losing a large plant are serious.

Some of the contingencies are:

- Fire, explosion, sabotage
- Earthquake or tornado
- Major pollution alert
- Plugging of water intakes with weeds or fish
- Impact by aircraft
- Major transmission outage
- Design, construction, or equipment defect.

On our system we try to limit the size of the largest plant at any time to a size such that, if the plant were disabled, we could continue to supply our load provided all other generation were available. That is, the largest plant could be as large as our contingency reserve which is about one-quarter to one-third of the annual peak load.

5.5 Other Thermal Plants

These include diesels and combustion turbines, which have the advantages of low capital cost, short construction lead time and quick starting, but the disadvantages of small size, low efficiency, and need for higher-priced fuels. We have installed them at our major thermal stations as sources of peak power and to ensure safe shut down of the thermal units in the event of a

transmission system outage. More units will be installed, but the capacity will be insignificant compared to the capacity of major units to be installed.

Another development in thermal units is the "combined cycle" unit in which high temperature gases are passed through a combustion turbine or magnetohydrodynamic generator and then exhausted through a boiler which generates steam for a conventional steam turbine. Such units might be useful on our system, but they are unlikely to displace conventional units to any extent. Since their space requirements and technical characteristics are much the same as conventional units it is not necessary to make any special provision for them in the long-range plans.

5.6 Unconventional Plant Locations

In order to solve some of the environmental problems associated with conventional practices, designers have considered locating conventional generating plants on unconventional sites. Some examples are:

- nuclear plants built on barges to be located off the Atlantic Coast.
- nuclear plants located underground or on artificial islands
- nuclear plants operated in conjunction with underground steam storage caverns
- pumped storage plants with the upper reservoir at surface level and the lower reservoir underground.

5.7 Other Sources

Fuel cells are essentially batteries supplied continuously with fresh electrolyte in the form of an energy fluid such as hydrogen. Although the principle has been known for over 100 years, fuel cells are still in an experimental stage. They may be a significant source of electric power in future, but they are unlikely to be commercially important for some years. It would therefore not be prudent to base any long-range plans on their use.

Solar power is often spoken of as a future source. Although the amount of solar energy intercepted by the earth is very large, the amount per square foot of the earth's surface is quite small. Solar stations are more likely to become practical in southern U.S.A. than in Ontario. A conceptual proposal for 1990 has been made to locate a 10,000 MW solar plant in a satellite in synchronous orbit over the equator, and to transmit the power to southern U.S.A. by microwave radio. Such a plant would require solar panels occupying about 40 square miles of space.

There are no tidal power sites in Ontario, and any such sites which may be developed on the east coast would probably be for local use, not for export to Ontario.

5.8 Major Imports

Ontario Hydro now imports firm power from Quebec and Manitoba under contracts which will expire soon. Opportunities for further firm purchases may arise from time to time. It is likely they will be for relatively small amounts of power and for short periods. Therefore, it is unlikely that they will have a substantial effect on the amount and timing of major generation additions in Ontario. Therefore, omitting them from the long-range plan does not invalidate the plan.

5.9 Assumptions for Long-Range Plan

The long-range plan is based on the assumption that the bulk of future generation requirements will be met by conventional steam plants of the fossil and nuclear types. Unit sizes will range upward from 750 MW and plant sizes will range upward from 3000 MW. The amount of power supplied from new hydro-electric generation or from imports will not be significant. Such a plan is flexible enough to allow for any amount of combined cycle units, breeder reactor units, or fusion units which may become commercially available within 20 years.

While there is no provision in the plan for large amounts of generation from fuel cells or solar cells, it is not expected that these sources will provide enough generation within 20 years to affect the plan. The onset of any influence from fuel cells and solar cells will be slow enough that

it can be taken into account by modifying the plan when necessary.

6. Generation Requirement

Ontario Hydro is committed to serving customers' demands with a high degree of reliability. We must do this with equipment whose individual reliability is far lower than the required reliability of supply. For example, the target for supply reliability is 99.96% while the availability of a major generating unit is less than 80%. We must therefore provide reserve, that is, we must provide generation totalling more than the load.

The calculation of the amount of generation needed to supply the load with a reliability of 99.96% (that is every day, except for one day in ten years), is done by a digital computer program called Loss of Load Probability (LOLP) which is described more fully in Appendix I. Since the calculation does not take into account all factors affecting generation reliability, it is necessary to use considerable judgement in deciding on a specific generation program. The amount of reserve generation needed to supply the demand varies from year to year depending on the size and availability of the new units being added, but it averages between 25% and 30% of the demand.

Since the load demand grows every year, it is necessary to install new generation at major generating stations every year in amounts approximating 125% of the load growth. For example, for the 7% growth pattern, the amount of new generation installed during 1983 must be 2250 MW and during 1993 must be 4650 MW. Over the period 1979 to 1993, approximately 42,500 MW must be installed.

7. Finding Suitable Generating Station Sites

Since the number of undeveloped sites now owned is small it will be necessary to purchase sufficient additional sites for developing at least 25,000 MW of generation by 1993, with some space for the additional generation required in later years. This in itself is a formidable task.

The ideal site for a new generating station would meet the following requirements:

- on the shore of a major lake

- reasonably level, with good foundation conditions
- close to the fuel delivery system (rail, navigable water, or pipeline)
- close to a major load centre
- in a location aesthetically and environmentally suitable
- in a location which will not interfere unduly with competing land uses.

Since some of these requirements are mutually conflicting, some trade-offs will be necessary. The Great Lakes region is one of the most favourable in the world for meeting these conditions. There are large quantities of water, and in many locations excellent rock foundations are available and population density is relatively low.

A site satisfying our requirements would be desirable for a major industry such as a steel mill or oil refinery. Our shoreline requirements would be suitable for a park. Our acreage requirements would yield more tax revenue if developed as a commercial or residential complex. Therefore, there will be considerable need for cooperation among Hydro, governments of all levels, special interest groups, and groups of the public, in selecting sites for major steam plants.

Our sites must be in locations which are acceptable according to Provincial Government long-range land use plans. In selecting a site and designing a generating station we must meet various Provincial requirements for air quality, water quality, recreation and conservation, and we must meet Federal requirements for nuclear exclusion areas, use of navigable waters, and hazards to aircraft. Municipal by-laws must also be considered.

The alternative plans for generation installation are given in Section 8. To meet these requirements, there is an immediate need for purchasing several large sites on the shores of the Great Lakes, to the east, west and north of the Toronto-Hamilton-Niagara area. By choice these should be suitable for construction over a period of years of plants of size 10,000 to 12,000 MW with once-through cooling. If enough such sites cannot be acquired, our second choice

should be to purchase sites suitable for 6000 MW, possibly with cooling towers.

It will be necessary to involve governments, special interest groups, and the public in our planning at an early stage. Even though the program is for site purchase only, it will be necessary to give some idea of the timing of construction and to explain how we propose to meet the environmental standards expected to be in effect at the time of construction.

8. Alternative Generation Programs - East System

8.1 Generation Program to 1983

The following major generating stations are authorized

Nanticoke 8 x 500 MW fossil units 1972-77

Lennox 4 x 500 MW fossil units 1975-77

Bruce 4 x 750 MW nuclear units 1976-79

The following are authorized subject to meeting requirements of government regulations and obtaining public acceptance.

Wesleyville 4 x 500 MW fossil units 1979-80

Pickering 4 x 500 MW nuclear units 1980-82

Bruce 4 x 750 MW nuclear units 1981-83

Bowmanville 4 x 750 MW nuclear units 1982-84

8.2 Additional Required Generation 1984-1993

The generation listed in Section 8.1 will be adequate for requirements up to 1983, but additional generation will be required starting in 1984. In this Section we describe several possible programs and the basic assumptions which go into them.

Alternative A - Load growth 7%

Fossil unit size 750 MW

Nuclear unit size 750 MW to 1990
then 1200 MW

Reserve basis 1 day in 10 years

Large new plants with 8 or 12 units ("Energy Centres"), with 10 year delay between each group of four units and the next. This is to allow 3 years operation of a four unit section before a decision is made to construct the next section.

Plant locations chosen to distribute generation over the load area.

This program, shown in Figure 2, requires generation at 9 new sites by 1993. Because of the 10 year interval between sections of a station, only Lennox, Bruce, Pickering and Wesleyville have reached the Energy Centre level, and there is considerable potential for expansion of the other sites after 1993.

Alternative B - This differs from Alternative A in that it permits Energy Centres to be developed without the need for a delay between sections to gain experience.

This program, shown in Figure 3 requires only 2 new sites by 1993. Most sites are filled up by 1993, there only being space available for plant sections required in 1994 and 1995.

Alternative C - This differs from Alternative A in that no energy centres are permitted and new sites accommodate four units only.

This program, shown in Figure 4 requires 11 new sites by 1993, and has no provision for expansion beyond 1993.

Alternative D - This is a speeded-up version of Alternative A as would be required if load growth were 10%.

This program, shown in Figure 5 needs 14 new sites, but because of the 10 year interval between sections of a plant, it has considerable flexibility for the future.

Alternative E - This is a slowed-down version of Alternative A, corresponding to load growth of 4%.

As shown in Figure 6 only two new sites are required.

Studies are being made of the possibility of developing about 1000 Megawatts of fossil generation from the Onakawana lignite deposits in northeastern Ontario. Because of the indefinite status of the project, it is not shown in Figures 2 to 6. If the project goes ahead, it will have the effect of deferring the whole generation program, but only by a period of one year or less.

8.3 Assessment of Alternatives

From the above, it can be seen that there are many alternative programs available, but that some of them will be rejected if certain ground rules are adopted. A comparison of A and B will illustrate this. If it is necessary to make a rigorous environmental analysis on each section of the plant before a new section is committed, then it is likely that about 3 years operation of the first section will be required before committing an extension. With about 7 years construction time, this means that the second section at a plant cannot come into service until 10 years after the first is completed. Most Energy Centres will therefore not be completed until after 1993. This is Alternative A and under these conditions Alternative B would not be permitted. However, if the primary objective were to keep the number of plants to a minimum until 1993, without being concerned about the effect on the program after 1993, then Alternative B would be preferred to Alternative A, and the environmental problem would have to be solved in some other way.

Alternatives A, D and E show the effect on the construction program of varying the load growth

between 10% and 4%. Alternative D, with 10% load growth sustained over 10 years or so, shows the large megawatt growth that results. It must be re-emphasized that the rate of load growth is not a factor over which we have any appreciable degree of control. If the demand rises at 10% it will be necessary for us to try to meet it.

9. West System Programs

In the context of this report, the requirements of the West System are relatively small. Therefore, no detailed listing has been included. In a general way, plans for the future envisage:

1. Possible extension of firm purchases from Manitoba Hydro.
2. Expansion of the existing Thunder Bay GS.
3. Development of a new thermal generating station - probably fossil-fuelled but possibly nuclear.
4. Ultimately, the development of large nuclear stations.

It might also prove desirable to develop in the 1980's some hydraulic generation or some combustion turbines; or, in the more distant future, a more substantial interconnection with the East System. To provide for a new thermal station a new site should be acquired immediately.

10. Transmission System Development

10.1 System Integration

Electric power utilities have developed in such a way that power is generated at a limited number of large central generating stations. But the ultimate consumers are scattered unevenly over the whole province, with the greatest concentrations being in urban areas. Therefore, a vast network of transmission and distribution lines is needed. High voltage lines of large capacity are needed to transmit the power from the major generating stations to terminal stations in the main load centres. On the Ontario Hydro system 230 kV lines are used for this purpose at present, but future new lines will be mainly 500 kV. From these terminal stations the power must be transmitted on

circuits of successively lower voltage and smaller capacity until it reaches the ultimate consumer.

The main transmission lines do not just run from each generating station to one particular load area. If they did each load area would be entirely dependent on one generating station, and in this case to provide acceptable reliability it would be necessary to use small generating units or carry large reserve generation. Considerable saving in cost can be achieved by interconnecting the generating stations with large capacity lines so that all generating stations and major load centres are integrated into one large network or grid. This is explained in more detail in Appendix I.

A province-wide grid has many advantages over a group of individual systems, such as:

1. Larger generating units can be used to achieve reduced cost at acceptable reliability. There is more leeway available to make trade-offs between unit size and amount of reserve.
2. The generation construction program can be concentrated into major projects at a few locations, rather than small projects at many locations.
3. The larger system is less vulnerable to the effects of sudden generator outages. Daily operating economies result from the need to carry less spinning reserve generation. Frequency and synchronous time control can be more precise.
4. Generators can be operated as system resources, without the necessity of matching any generator output to any specific area load. Some generators can be operated on base load and others varied in output to match minute-to-minute system load variations without having to take into account the variations in local loads.
5. It is easier to achieve such economies of daily energy production as utilizing the full available output of hydro-electric plants at all times, and using low-cost nuclear plants in preference to high cost

fossil plants at times when all system generation is not needed. It is easier to make generation adjustments required to comply with pollution alerts.

6. Maintenance schedules can be more easily co-ordinated.
7. More resources are available to mitigate the effects of catastrophes.
8. No load area is dependent on the reliability of a single generating station.

The cost involved in achieving the results listed above is that of a more extensive and complicated transmission network. The level of reliability of supply to the loads can be very high, but a high reliability is required in the transmission system to achieve this.

Over the years our system has developed by integration from a number of small isolated systems into an interconnected system covering the whole province. Our long-range plans are based on the assumption that integration will continue to be achieved.

Although an integrated system implies a transmission grid interconnecting all load centres, the amount of transmission required is partly dependent on the location of the generating stations in relation to the load areas. A system in which the generating stations are distributed throughout the load area and generally near load centres will require fewer miles of transmission than one in which the bulk of the generation is located in one geographical area somewhat remote from any load centre. Thus generation and transmission cannot be planned independently.

10.2 Interconnections with Neighbouring Utilities

The numerous advantages of integration within a system like Ontario Hydro's as outlined in the previous subsection, can be enhanced when there are high capacity interconnections to large neighbouring utilities. We now have interconnections with utilities in Quebec, Manitoba, New York and Michigan, and through them are interconnected with most major North American

utilities. However, since we wish to be relatively independent of entities outside our own province, we do not depend on outside utilities for part of our generation reserve requirements. Hence, the advantages of interconnections as we plan them, are less than the advantages of internal integration.

10.3 Transmission System Reliability

Because of the importance of electricity in daily life, it is necessary to provide a very high level of reliability of supply to the major load centres. As outlined in Section 6, the problem in achieving adequate reliability in the generating facilities is one of having enough reserve so that, except for a very small percentage of the time, there is always enough generation available in operable condition to supply the load demands. Likewise with transmission, it is necessary to have enough reserve that even with lines out of service the remaining lines are not loaded beyond their current carrying capability. Another important aspect of transmission reliability is the security of the system, that is, its ability to recover from the effects of sudden electric stresses imposed on the lines by lightning, equipment breakdown, failure of generating units, etc.

The security of proposed transmission networks is calculated by a process of mathematical simulation using a digital computer. A model of the transmission system is set up, and the power flows in all circuits are calculated. Then a simulated fault is applied (e.g. lightning striking two circuits on a double-circuit tower line) and the behaviour of the system over the crucial next few seconds is calculated. From this, it is possible to determine whether the system can recover from the disturbance or whether instability will result, producing violent reversals of power flow which will lead to separation of generators from the system and loss of supply of power to loads. From computer studies it is also possible to determine whether the fault currents or the ensuing steady state currents are likely to cause damage to any system components. Alternative proposed systems can be analyzed in this way, and only those meeting the security requirements will be selected for further comparison for selection of the final scheme.

It is not possible to make a transmission system completely secure against all possible contingencies. Therefore, for some of the more severe faults which have a low probability of occurrence (such as loss of all lines on a right of way) the system is designed to limit the geographical extent of the resulting failure in power supply and to facilitate rapid restoration.

10.4 AC vs DC Transmission Systems

In the 19th century, when power systems were small, both alternating current (AC) and direct current (DC) systems existed. As the size of systems increased, the simplicity of AC rotating machines and the flexibility in choice of voltage provided by the transformer greatly favoured AC systems. DC systems became all but non-existent until the 1950's when the development of large capacity static devices (mercury arc valves) caused renewed interest in use of DC for specific transmission links in predominantly AC systems. Such links are economically attractive for certain applications, where the saving in use of DC transmission more than offsets the extra cost of the mercury arc conversion equipment at each end of the link.

Two recent installations which typify an application which might be suitable in Ontario are:

1. In London, England - A radial underground link from a generating station to the city centre.
2. In Manitoba, a radial overhead link from a group of generating stations to Winnipeg.

Both of these installations are of a developmental nature and their reliability has not yet been proved.

Most transmission links in Ontario must be terminated or tapped every 25 to 50 miles for interconnection with other links or for supply of local load. Such application is simple with an AC system but is extremely complicated with DC.

While there are potential future applications for DC transmission links in Ontario, the technical economic and reliability aspects militate against

any immediate adoption. Therefore, the expansion of the Ontario transmission network during the next few years must be with AC systems.

Because an extensive AC transmission network exists, and because it will be augmented with AC during the next few years, it seems reasonable to assume that the transmission system will continue to be predominantly AC, although there may be some DC links.

World-wide developments in DC transmission are being closely followed by Ontario Hydro. The present long-range plan is flexible enough that it can encompass the addition of DC links should they eventually become economic and sufficiently reliable.

10.5 AC Transmission Voltages

Throughout the history of the electric utility business, there has been pressure to obtain greater transmission circuit capability by pushing transmission voltages upward, and to advance technology to permit increasing voltages. In keeping with this, Ontario Hydro first used 115 kV in 1910, 230 kV in 1928 and 500 kV in 1966.

When the transmission system for the Moose River generation was being studied in the late 1950's, it was felt a higher voltage than 230 kV could be justified because of the amount of power and distance involved. A comparison was made of

- 345 kV the highest commercial voltage in United States
- 400 kV the highest commercial voltage in Europe
- 460 kV a new voltage level in the research and development stage

Although 400 kV and 460 kV appeared about equal in our studies, the higher level was chosen because of possible long-term advantages. Subsequently, the level was raised to 500 kV (nominal) 550 kV (maximum) to be in keeping with American National Standards.

Studies of a possible extra-high voltage transmission system for Southern Ontario were

carried out over a period of years starting in 1959. It was envisaged that by the 1970's the 230 kV network would become so complex that a new overlay system would be required. The level of 500 kV was considered best because:

- (a) It appeared to have an adequate balance between cost of construction and complexity of the network.
- (b) It would match the 500 kV system already authorized for the Moose River generation.
- (c) It was the highest voltage in commercial use anywhere, and research on higher levels was in the earliest stages.

Subsequently, utilities in Quebec and U.S.A., who were using 345 kV transmission and for whom 500 kV was not attractive, intensified research on a system of 700 kV (nominal) and 765 kV (maximum). We therefore reconsidered our decision to use 500 kV and confirmed it on the basis of cost and reliability. Transmission at either voltage would have the same current capacity limit because of limitations in design of extra high voltage circuit breakers and other station equipment. Thus, a 765 kV circuit could only carry 40% more power than a 500 kV circuit. However, consideration of mechanical design of towers indicated that it would be possible to build an aesthetically acceptable 500 kV double-circuit tower but that a 765 kV double-circuit tower would be so massive as to be unattractive. Thus, a 500 kV double-circuit line could carry 40% more power than a 765 kV single-circuit line, at the expense of some additional complexity in switching. Thus a 500 kV network could be provided using less right of way than a 765 kV network.

11. Overhead vs Underground Construction

11.1 Overhead Circuits

Overhead circuits have been the mainstay of the transmission system for many years. Over 99% of all transmission mileage in North America is overhead. The predominance of overhead is the result of low cost, acceptable performance, and easy maintenance.

The standard type of tower, which has been in use for more than 60 years, is built up of a lattice of steel members. This design is very efficient in the use of steel, but the triangular configuration of the lattice members presents a confusing pattern which is displeasing to many people. In recent years, a number of new designs have been prepared which, although less efficient in the use of steel, present a more integrated appearance. The most common type is a steel pole structure with crossarms in a sweeping gull-wing shape.

Selection of line route is one of the major problems in construction of a transmission line. Because air is used as the insulating medium it is necessary that we have control over the use of the airspace below and adjacent to our conductors. This means that we must acquire control of the land, either by ownership or by easement. There are several major objections raised by property owners such as taking the land "out of production", erecting "unsightly" structures on the land, and interfering with the ecology. The aesthetic problem is tackled by careful selection of a route which is seen regularly by the smallest number of people, and which is hidden from view by adjacent trees or landforms. The land-use problem is tackled by avoiding interference with existing buildings, by trying to arrange for continued farming of rural lands, and by trying to encourage other uses which are compatible with our safety and security requirements. The ecology problem is handled by minimizing changes to the land used for the right of way, and by avoiding sensitive areas.

Construction of the line requires selective clearing of those trees which would interfere with line insulation or be a danger to the line if they fell. Clearing of tower sites is also required. Access is required for equipment to drill for tower foundations and to deliver tower materials. Depending on terrain, conductors may be strung by laying them out on the ground and then raising them at each tower, or they may be pulled in directly under tension in runs several miles long. Cleanup after construction includes tree and shrub planting at road crossings. Routine maintenance of the right of way includes selective weed-cutting and brush and tree trimming where there is no joint use. The line is regularly patrolled, in most

cases by helicopter, to spot broken insulators and other potential security hazards.

There has been considerable study of the possibility of establishing utility corridors, rights of way set aside for joint use by electric power utilities, highways, railways, pipeline companies, etc. While the joint use of a right of way by two entities is quite common, it is difficult to find significant distances over which three or more entities can follow the same route. There is a lack of unanimity on the desirability of routing transmission lines along highways, because many people consider such routing spoils the aesthetics of the highway.

Overhead circuits have an acceptable level of reliability. They are subject to a number of short outages due to lightning, ice-storms, or the combination of damp weather and contaminated or broken insulators. Since overhead lines are generally equipped with automatic reclosing many of the outages last for only a few seconds. Older lines are liable to broken skywires or broken conductors, which take several hours to repair. Major outages resulting from damaged towers or several broken conductors are rare, and are usually the result of tornadoes or impact by vehicles.

11.2 Underground Circuits

Underground cable for voltages up to 345 kV has been available for some years, but because of its high cost very little has been installed. Short lengths of 500 kV cable have been manufactured recently but there has not yet been time to prove their reliability. The circuit mileage of cable of 115 kV and higher is less than 1% of total transmission in North America.

The high cost of cable circuits results from the high costs of manufacture and installation. The only type of cable in common use at voltages of 115 kV and higher is one which the insulation is built up by winding layer upon layer of thin paper tape, impregnating it with oil, and providing some sort of protective sheath.

There are many variations in design, some of which are intended for direct burial or use in concrete or fibre ducts, and some of which are intended to be pulled into a steel pipe.

There are many installation problems, such as:

- Laying out a route which does not interfere with other utilities.
- Trenching, often in a busy street.
- Laying steel pipe with smooth inside joints and with the outside protected against corrosion.
- Backfilling with suitable material to facilitate the conduction of heat away from the pipe.
- Keeping the pipe absolutely dry while pulling cable into the pipe.
- Splicing cable lengths by hand labour every one-half mile or less. This involves hand application of paper tape insulation as free of moisture and air spaces as in the cable itself.

In contrast to overhead, the use of underground cable in rural areas would require complete clearing of a right of way so that trenching machinery could go to work; and severe limitations on later joint use of the right of way so that adequate cable cooling could be achieved, the possibility of damage would be reduced, and repairs could be effected.

While an underground cable is out of sight for most of this length, long high-capacity cables would need considerable space above ground at intervals for auxiliaries such as:

- heat exchanger stations for cable cooling every 1 or 2 miles
- reactor stations for absorbing charging current every 5 or 10 miles

Cables in service to-day have acceptable reliability. Insulation failures are very rare, being confined mainly to where the sheath has corroded and moisture has been able to enter. The most common type of failure is the dig-in, where the cable is damaged by a bulldozer, shovel or pile driver. The damaged spot is usually easy to locate but repairs may take several days. Such repairs

often require replacement of a stretch of cable. The necessary cable splicing involves replacement of the machine-wrapped paper insulation with hand-wrapped paper tapes. A dry atmosphere and skilled tradesmen are necessary. Land slippage due to flooding or earthquake is about the only other catastrophe which can affect all circuits on the same right of way.

Considerable research is being done on cable design. Short-term research is aimed at modest improvements in oil-paper cable, such as improved papers and improved methods of heat dissipation. Long-term research is directed at the use of other types of insulation, such as extruded plastic, air or other gases, and at artificial refrigeration for greatly increased heat transfer. The most promising development is coaxial cable insulated with sulphur hexafluoride (SF₆), which is commercially available for 345 kV buswork but which still requires development for use as underground cable. Ontario Hydro's major original research effort is directed at development of an air insulated duct type cable, in which three tubular conductors are enclosed within a large pipe filled with air at atmospheric pressure. One of the more radical schemes being investigated is cryogenic cooling which involves operating the conductor at a temperature colder than 200°C below zero, where conductor resistance is negligible and current carrying capacity very large.

11.3 Choice of Overhead vs Underground

Because of its high cost, the use of underground has been limited to downtown core areas of major cities and a few areas of high scenic value. For example, about 60% of the 115 kV circuit mileage in the City of Toronto is now underground, and there are short stretches of underground cable in the egress transmission from Saunders GS and Lakeview GS.

In recent years there has been increasingly vocal criticism from the public about the "visual pollution" of the landscape by overhead power lines. While their comments are valid at scenic spots and in the vicinity of large stations, it is the feeling of most utility people that modern designs of transmission lines on well-chosen routes constitute a minor disfigurement of the landscape which is acceptable to most members of the public.

It is felt that expenditures on lengthy underground circuits through ordinary countryside are not an efficient use of capital.

Areas in which consideration should be given to avoiding overhead transmission are listed in two priority categories. The advantages and disadvantages of each case should be considered separately in making a decision for underground versus overhead.

CATEGORY I

The highest priority should be given for the underground transmission facilities in the following areas:

- (a) Central business districts of cities and towns.
- (b) Developed residential areas where to acquire a right of way for an overhead line would mean the removal of more than a few homes.

CATEGORY II

The next priority should be given for underground transmission in the undernoted areas. However, where these areas are compatible with multi-use of the right of way, improved appearance overhead structures should first be considered.

- (a) Parks formally designated and established for their natural, recreational, scenic or cultural value by federal, provincial or local governments.
- (b) Public and semi-public facilities such as schools, universities, medical facilities or other institutions.
- (c) Existing light industrial and commercial areas.
- (d) Areas which are visually saturated by existing transmission or station facilities (e.g. crossovers and station entrances, rights of way with a large number of tower lines).

For our long-range plan, it is assumed that most 230 kV and 500 kV line mileage will be overhead. Any extensive use of underground cable, particularly 500 kV cable, would result in significant changes in power system design and would likely require changes in the long-range plan.

11.4 Use of Existing Rights of Way

Some existing rights of way are wide enough that if existing circuits were removed new 500 kV circuits could be built on them. In urban and suburban areas, the possibility exists of replacing the existing installations with 500 kV overhead and 230 kV underground. Such rebuilding would be costly, but would have the advantage of not requiring a new right of way for the new 500 kV circuits.

12. Subtransmission and Distribution

Lines at voltages of 44 kV and lower are not the concern of this report. However, they do contribute to the general environmental problem because of their ubiquity. As with higher voltage transmission lines, underground provides a possible solution at increased cost. Underground eliminates the clutter of wires, but along many streets the poles must be retained for street lighting. Much has been done in recent years in the design of pole lines which intrude less on the urban scene.

13. Stations

Switching and transformer stations are necessary to provide branching points in the transmission system, to permit isolation of faulted lines and to permit transformation of power between different voltage levels. Typically, transmission lines converge on the stations from several directions.

With the objective of enhancing the station appearances, new switchyard designs have been developed which permit considerable reduction in the height of 500 kV, 230 kV and dual-element stations where this is required. This is achieved by the adoption of solid-steel structures and the elimination of the strain bus. Landscaping, and in some cases the use of colour, may also be used to reduce the visual impact of the station.

In urban centres some smaller stations have been enclosed in a housing of brick or architectural concrete. Sulphur hexafluoride (SF6) insulated buswork and switching is a promising development now becoming commercially available. Its use will permit considerable reduction in area and volume of stations. Ontario Hydro is keeping in close touch with its development towards meeting its reliability and system requirements. One 115 kV station has been ordered for downtown Toronto.

14. Transmission Development Program

Section 8 outlined five generation development programs. With each of these there could be several alternative transmission development programs, each with sub-alternatives for routing of specific lines. Thus there could be dozens of long-range transmission systems. In this report, three representative programs are shown in Figures 7, 8 and 9. For simplicity, the Figures show in a conceptual way the 500 kV main transmission only. No attempt was made to show exact routes.

The timing of the new circuits is difficult to specify, but it is expected that by 1983 some circuits will be required on most of the routes shown.

15. Conclusions

1. Ontario Hydro's electric load is expected to double by 1983 and may redouble by 1993. To maintain an adequate and reliable supply, a major expansion of the power supply system will be necessary.
2. In designing the system, it will be necessary to make many trade-offs within and among the technical, ecological, social and group action areas. The basis for these trade-offs must be determined in co-operation with the Government and through the public participation process. This will lengthen the lead times required for projects.
3. As a basis for long-range planning, it should be assumed that most of our new generation requirements in the next 20 years must be fulfilled by construction of mainly nuclear stations supplemented by fossil stations.

4. Because of the long lead times in purchase of sites and development of generation, sufficient new sites and main transmission corridors should be acquired now to satisfy our requirements for the next 20 years.
5. A major bulk power transmission system will be needed, and plans for the next 20 years should be made on the basis that this will be 500 kV AC.
6. Because of the state of development, reliability and cost of 500 kV cable, all early 500 kV circuits should be overhead. Long-term plans should assume overhead construction except in critical areas. Considerable effort must be expended to minimize the effect of overhead circuits on land use, aesthetics, and the environment.

APPENDIX I

Reliability

I-1 Introduction

Electric utility customers have come to expect an abundant supply of electric energy with a very high level of reliability. Many industrial processes are set up with the expectation of 100% continuity of supply, and an interruption of only a few minutes will disrupt the flow of the process and will result in significant financial losses.

In the world of commerce, in which transportation systems such as subways and elevators are entirely dependent on electric utility service, even a short interruption can cause considerable personal inconvenience. Many farms are dependent on a reliable electric supply and long interruptions create hardship because of the use of electricity for such things as hatching chickens and milking cows. Although residential customers can usually tolerate short interruptions, long outages can disrupt heating, cooking, and refrigeration. A few commercial and industrial establishments consider it economical to provide auxiliary generation as a back-up to the utility supply, but those who do usually provide only a minimum amount of essential services.

Utility-produced electricity is important in many non-electric processes, where it is depended on to perform an auxiliary or control function. For example, automobiles obtain their energy from gasoline and are independent of utility electricity, but utility power is used to pump gasoline at service stations and to operate traffic lights. A utility power failure can therefore cause traffic chaos. Likewise the source of energy for space heating in most houses is gas or oil, but most furnaces will not operate satisfactorily without a supply of utility electricity.

The cost of reliability is a major item in the cost of electric supply. Therefore, it is reasonable to ask whether the current high level of reliability is justified. If the level were lowered, the saving in the cost of the electric utility's facilities would probably be greater than the losses in its revenues that would result during times that electric supply to its customers is interrupted; but it is believed the penalty to the electric utility's customers due to the more frequent and lengthy interruptions in supply would be

very much greater than the benefits they would gain from their reductions in payments to the electric utility.

Thus, the overall economic solution to the question of the approximate reserve level requires estimation of the savings to the utility of successively reducing its reliability of supply and comparing these savings with the resulting successive losses to its customers. This is simple in principle, but it is impossible in practice. For although the savings to the utility can be determined, the real losses to its customers are unknown.

Electric utilities have made many attempts to resolve this problem, but they have been unsuccessful because of the extremely complex economic nature of their customers. To some extent, the existing levels of reliability reflect many years of day-to-day interaction on this matter between the electric utilities and their customers.

I-2 Definition of Reliability

I-2.1 Reliability

In order to be used in mathematical calculations, reliability must be defined as precisely as possible. According to a standard definition, reliability is "the probability of a device performing its purpose adequately for the period of time intended under the operating conditions encountered." Probability is a key word in the definition, because probability mathematics is used to evaluate reliability, and the answers are not intended to state whether or not a given piece of equipment will be available at a given time, but only the odds that it will be available.

Because of the complexity of power systems, it is not possible to apply this strictly mathematical definition to power system reliability. Accordingly, power system reliability is divided into two aspects: availability which is amenable to mathematical analysis, and security which is not.

I-2.2 Availability

The level of reliability required in the supply of electric energy is considerably higher than the reliability of the generators and transmission lines which are the essential components of the supply system. It is therefore

necessary to provide redundancy in these components to ensure that there are enough components in operating condition to permit full supply. This aspect of reliability is known as "availability". Availability is capable of being calculated using probability mathematics. A generator is said to have 80% availability when there is an 80% chance that at any particular time it will be capable of being operated and a 20% chance that it will be defective or on routine maintenance. The target for generation availability is 2399/2400 or 0.9996 meaning that there is only one chance in 2400 that it will not be adequate to supply all system demands. Since there are about 240 heavy load days in a year, this latter is often interpreted as saying that there will be one day in 10 years when the demand cannot be met.

Some factors affecting the availability of the components, which must be taken into account in calculating the availability of the system, are:

- (a) Components are subject to periodic breakdown because of wear and tear, inherent defect, bad weather, etc.
- (b) To reduce the incidence of breakdowns, components must periodically be taken out of service for preventive maintenance.
- (c) There is a possibility of failure of supply of critical materials such as fuel, heavy water, etc.
- (d) There is the possibility of strikes.
- (e) Construction schedules may lag on new equipment.
- (f) New equipment is subject to "shakedown" problems.

I-2.3 Security

System security, which cannot be calculated precisely, is a measure of the ability of the system to withstand the stresses imposed by sudden shocks, such as loss of large generators, equipment malfunction, operating error, or weather effects. A transmission system may have adequate availability, that is there might be enough components to supply the load under normal steady

state conditions. It might even have adequate availability to supply steady state loads with a circuit removed. However, if that circuit is removed by a fault, there will be a severe stress placed on the system for a few seconds because of changes in power flows occasioned by the fault. The system has security if it is able to sustain these power swings and eventually settle down to a new steady state. It does not have security if the power swings are amplified by the system and lead to instability, i.e. disconnecting of generators, and loss of ability to supply all loads.

Security is not directly related to the number of circuits available. Other factors are also important, such as speed of clearing faults.

I-3 System Aspects of Reliability

An electric power system may be broken down into three major components: generation, transmission, distribution. In order to have adequate reliability of supply, each of the three components must have a certain measure of availability, and the transmission component must have adequate security. While it would be desirable to treat reliability on an overall basis, varying the reliability of the components to get the highest overall reliability at a minimum cost, this is much too difficult in practice. Therefore, the reliability of generation, transmission, and distribution components is calculated separately, using different techniques.

I-4 Types of Faults Considered

A complete calculation of reliability should include outage rates for all possible types of faults, no matter how improbable. However, only limited statistics are available to cover such improbable events as war, invasion, flood, fire, earthquake, or major design defect. Because of the low probability of such events, omitting them from the calculation has a very small effect on the calculated value of availability. When a decision of what facilities to provide is made on the basis of calculated availability, omission of improbable events does not invalidate the calculation.

Many decisions, particularly where security is involved as in the transmission system, cannot be made on the basis of calculated reliability. In such cases, each type of fault must be assessed for its possibility, the seriousness of its effect, and the cost of providing

against it. The decision must then be based on judgement.

I-5 Generation Reliability

I-5.1 Calculation of Reserve Requirement

Calculating the availability of generation components follows well-developed and fairly straightforward probability techniques. The generation availability calculation made by Ontario Hydro is essentially the same as that made by most other utilities in North America. It is aimed at determining the generation requirements such that the peak daily generation available (i.e. not under emergency repair or routine maintenance) will theoretically exceed the daily peak load every day except for 1 day in 10 years. This may be roughly described as a reliability of 2399 days in 2400 or 99.96%.

The mathematical computation is known as "Loss of Load Probability" (LOLP) and is briefly described as follows:

1. For each month of the year a load probability distribution of the daily peak loads is made up from historical records.
2. For the month in question, a listing of each generator and its forced outage rate is made and a calculation made of the probability that any given combination of generators (and hence a certain megawatt capacity) will be available. This is then arranged into a probability distribution of available capacity on any day of the month.
3. The distributions of 2 and 3 are merged and a calculation is made of the probability that the peak generation available will be less than the peak load. If this differs greatly from 1/2400, the amount of new generation is adjusted.
4. The calculation is repeated for all months of the year, and the generation program which is largest of the twelve is chosen as the annual requirement.

The LOLP calculation, while it is useful in comparing generation reliabilities for different

years and different programs, does not measure reliability in absolute terms. It does not include probabilities of several important factors such as:

- In-service dates may fall behind schedule for many reasons, such as construction or purchasing difficulties, technological problems, natural catastrophes, strikes, or delays in obtaining necessary Government approvals.
- Outputs of units may be less than anticipated due to changes in environmental regulations, shortages of fuel or heavy water, strikes, shortage of maintenance staff, etc.
- Coincident or overlapping successive failures of generating units may occur because of cross-link factors (such as failure of control or auxiliary systems common to two or more units) or common-mode factors (such as common design defects in two or more identical units)
- It may not be possible to transmit the full available output of all generating units to the load centres at all times because of inadequacies or contingencies in the bulk power transmission system.
- Firm power purchase contracts may be curtailed because of deficits of generation on the supplier's system.
- Actual loads may be higher than forecast.

I-5.2 Sample Calculation

As an example of the reserve generation requirements, and the effect of unit size on reserve, the following hypothetical calculation is offered.

Consider a system of 500 MW peak load, with the usual hour-to-hour load variation to be supplied by thermal generators which are expected to be forced out of service for 10% of the time. Probability calculations show that if a plant contained six 100 MW units, all six would be available 53% of the time, and any 5 or more would be available 89% of the time. Thus, if this 6 unit

plant were used to supply a 500 MW load, it would be adequate only 89% of the time, and the loss of load probability would be defined as 11% or 1 day in 9 days. This is hopelessly inadequate by present day standards.

To obtain the target 99.96% availability would require ten 100 MW units, or a reserve of 100%. The amount of reserve could be reduced if the unit size were smaller in relation to the load. For instance it would take sixty-four 10 MW units to provide the same reliability, or a reserve of only 28%.

The amount of required reserve can also be reduced by integrating several small systems into a single system. For example:

- Ten separate 500 MW systems would require ten 100 MW units each for a total of 100 units, 100% reserve.
- One integrated 5000 MW system would require only sixty-four 100 MW units, or a reserve of 28%.

I-6 Transmission System Reliability

Determining the reliability of the transmission system is very difficult because it depends on "security" to a greater extent than on "availability." It is not possible to calculate security using probability mathematics. Therefore recourse must be had to setting up a simulation of the system under normal and faulty conditions and determining whether or not the system is likely to recover to a stable steady state after experiencing the disturbance of certain severe faults.

The bulk power system must therefore be adequate to carry the load imposed on it by any of the whole gamut of normal conditions, and must have a reserve capacity to be able to handle the sudden changes resulting from the forced outage of generation. Since the transmission system itself is made up of elements which are liable to fail, there must be a further reserve capacity to handle the effects of failure of elements of the transmission system.

Transmission elements are much more reliable than generators. A line 100 miles long might suffer

four or five outages in a year, but the total outage time will be much less than 1%. However, there are a large number of lines, breakers, and transformers on the system. Therefore, the number of incidents per year when a fault occurs on the transmission system is rather large. The percentage of these faults which cause the system to become overloaded or unstable and lead to the dropping of load must be kept small. Theoretically it should be possible to determine all the outages or combinations of outages of equipment which could result in loss of load and to determine the probability of occurrence of each of those events and hence the total probability of loss of load. In practice the transmission network is much too complicated to apply this technique. Hence the method used to assess system adequacy is one called "contingency testing." The transmission system is simulated mathematically on a computer, and the effects of certain carefully-selected severe faults are determined. A transmission system which is adequate for these faults will likely be adequate for all other faults which occur with reasonable frequency.

We have agreed with our neighbouring utilities on a common basis for assessing the adequacy of our transmission system. For specified faults which have a reasonable probability of occurrence (such as a simultaneous fault on two circuits of a double-circuit line, or a fault on one circuit which is cleared by back-up breakers) the system as a whole must withstand the transient and post-fault steady-state loadings resulting from the fault without any remaining equipment being overloaded beyond thermal capability or to the point where it might trip out and lead to tripping of further facilities. Under these conditions there must be no effect, other than a momentary voltage surge, to any customers except those connected directly to the faulted line. For more severe faults which have a lower probability of occurring (such as loss of all the lines on a right of way) the system should be designed to limit the geographical extent of the failure.

The extent to which security should be provided against catastrophic transmission failures is difficult to rationalize. Such failures are rare, being the results of tornadoes, ice storms or impact by aircraft for overhead lines, or earthquakes or land slippage for underground cables; but they affect all circuits on a right of way. The safest way would be to route each circuit on its own right of way, but this would use up considerable land. For our 500 kV system, the best compromise at present is to set a normal limit

of three single-circuit or two double-circuit lines on one right of way. This will still require the use of two rights of way on heavily-loaded routes such as those entering the Toronto area.

Another complicating factor in reliability studies is construction lead time. Studies must be made for conditions far enough ahead that there is time to build any indicated facilities. The longer the lead time, the farther ahead the loads and system conditions must be predicted, and the greater the chance that the prediction will prove to be in error. While the simulation can give a fairly accurate picture of the system performance for the given conditions, the longer lead time will increase the probability that the chosen system will prove to have been overdesigned or underdesigned.

Generating station site selection has an important bearing on reliability because judicious selection can reduce both the amount of power transmitted and the distance, hence reducing reliability problems.

Efforts are directed at designing a strongly integrated and interconnected system with strategically located generating sources and well-balanced network design. For such a system, separations and loss of load should be rare, and the major part of the system is expected to survive such separations, with loss of load being confined to local areas.

APPENDIX II

Transmission Voltages

Throughout the history of the electric utility business there has been a pressure to push transmission voltages upward. In keeping with this Ontario Hydro first used the 115 kV voltage level in 1910, 230 kV in 1928 and 500 kV in 1966.

Planning studies which established the 500 kV level began in the late 1950's when the transmission system for the Moose River Generation was being planned. The only transmission in the area at that time was a weak 115 kV system so there was freedom to choose any voltage for the new transmission on the basis of economic and technical factors. At that time 230 kV was our highest standard voltage, 345 kV had been established in United States, 400 kV was in use in Europe; a 500 kV line was under construction in USSR and 460 kV was being studied in United States. For the Moose River generation extensive studies were carried out of alternatives of 345, 400 and 460 kV. These studies showed that 400 and 460 kV were equal in cost and both were superior to 345 kV. The higher level of 460 kV was chosen on the basis of intangibles:

- (a) It would have a greater margin of safety and stability.
- (b) It was considered within the capabilities of North American manufacturers.
- (c) It was more likely to become a North American Standard.
- (d) It would be more useful in future in Southern Ontario.

Eventually 500 kV nominal, 550 kV maximum was chosen as American Standard, and we were able to uprate our 460 kV system to 500 kV without significant design changes.

A level in the vicinity of 700 kV was not considered in the Moose River studies because there had been no research work done on 700 kV transmission at the time and therefore there was no likelihood of that level becoming commercially available in time to be used.

In 1959, just after the 460 kV level was decided on for the Moose River generation, studies began on the long-term requirement for a new level above 230 kV in Southern Ontario. It was envisaged that long-term continuation of the 230 kV level would result in a very complex network with

many lines required to handle the power flows, and with very high levels of fault current. The level of 500 kV was chosen for the following reasons.

- (a) It appeared to have an adequate balance between cost of construction and complexity of the network.
- (b) It would match the 500 kV system already authorized for Moose River generation.
- (c) 700 kV and higher voltages were still in an early stage of development.

The neighboring utilities in Quebec, New York, and Michigan had all adopted voltages in the range of 300 to 345 kV as their main trunk voltage. Their studies have therefore shown that 500 kV is not enough different from 345 kV to be worthwhile and they have adopted 700 kV nominal 765 kV maximum as their next voltage level. We have reviewed our studies for our Southern Ontario System, and decided that 500 kV is better than 765 kV for the reasons outlined in the following.

When the change was made from 230 kV to 500 kV it was possible to double the permissible currents in the lines while still maintaining adequate control of the network. Thus a 500 kV circuit will carry at least four times the power that a 230 kV circuit will carry. However, because of limitations in station equipment such as circuit breakers, it is not feasible to further increase the current when going to 765 kV. Thus the power-handling capability of a 765 kV circuit is only 1.4 times that of a 500 kV circuit.

It is possible to construct 500 kV double-circuit tower lines of acceptable appearance, but 765 kV double-circuit towers have not been designed yet. Because of the large electrical clearances required, a 765 kV tower would be very massive and unattractive in appearance. It is therefore likely that we would use only single-circuit towers in the early stages of a 765 kV system.

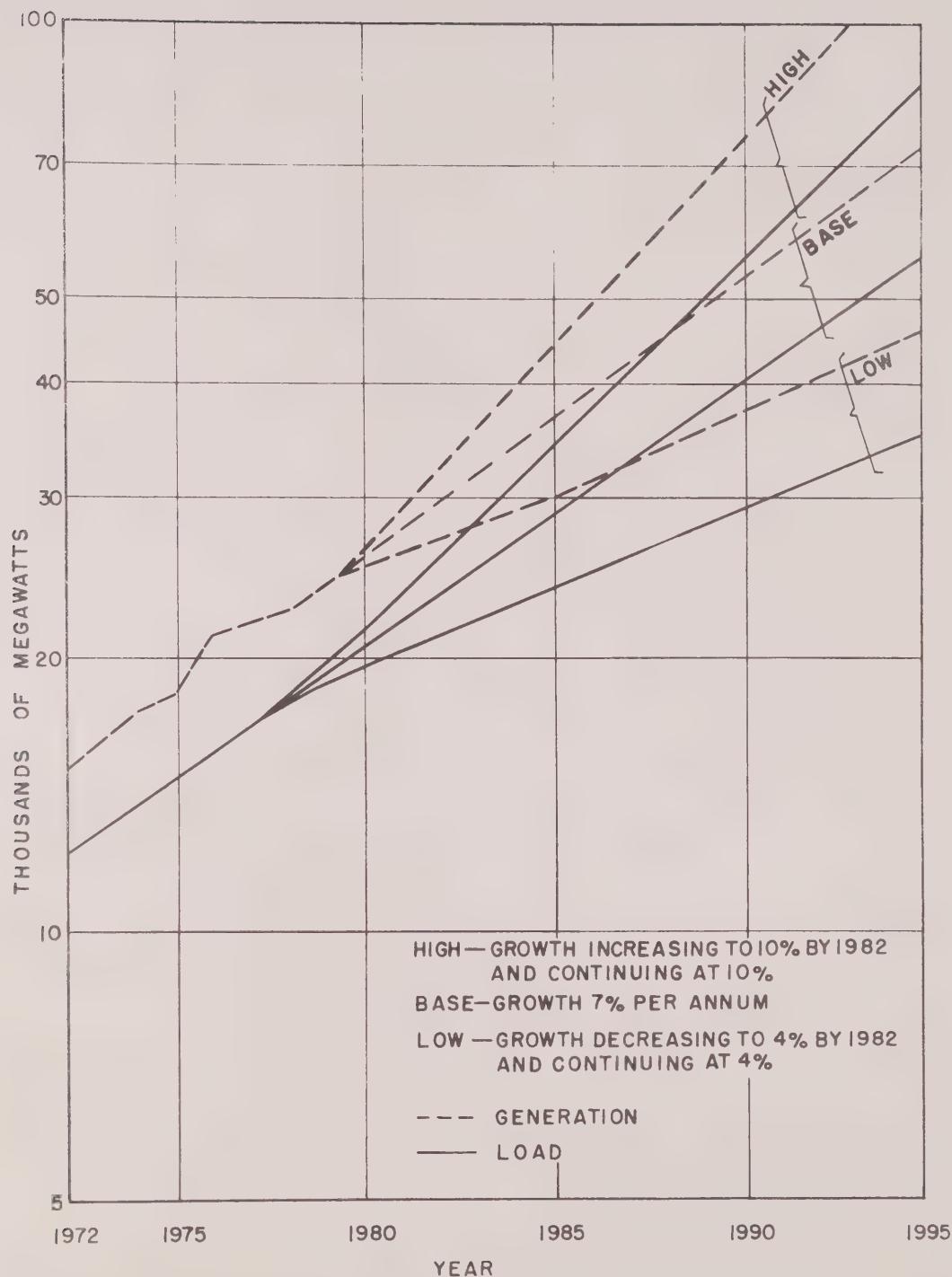
The transmission criterion adopted by the Northeast Power Coordinating Council, of which Ontario Hydro is a member, is that the system must be adequate for the loss of a tower line at a time when another circuit is already out of service. If double-circuit construction is used at 500 kV, one double-circuit tower line has no firm capacity because both circuits can be removed by a double-circuit fault. A system of two double-circuit 500 kV lines has a firm capability of 3800 megawatts for a typical system, because it still has one circuit in service after meeting the NPCC criterion of loss of one circuit plus one double-

circuit tower line. For 765 kV single-circuit tower lines, it takes three lines to have any firm capacity (in this case typically 5300 megawatts) because in this case there is one circuit in service after loss of one circuit plus one single-circuit tower line. For larger systems, the firm capability increases at the rate of 7600 megawatts for 500 kV double-circuit or 5300 megawatts for 765 kV single-circuit lines. The firm power transfer capabilities of typical 500 kV and 765 kV systems are illustrated in the following tabulation.

<u>Number of Tower Lines</u>	<u>Firm Capability in Megawatts</u>	
	<u>500 kV</u>	<u>765 kV</u>
1	0	0
2	3800	0
3	11400	5300
4	19000	10600
5	26600	15900

The 500 kV system would require less right of way than the 765 kV. The 500 kV network would be somewhat more complex because it would require more station switching, but it is expected that the complexity will remain at a reasonable level for many years.

Our studies indicate that 500 kV will be adequate as a main trunk voltage level until at least 1990. If a new level is adopted, it will probably be in the 1100 to 1500 kV range. The present 230 kV system will continue to support the 500 kV system for some time, but eventually most 230 kV circuits can be fully utilized in supplying area load, or will be removed to make way for further 500 kV lines.



ONTARIO HYDRO
EAST SYSTEM
ESTIMATED PEAK LOAD
AND GENERATION

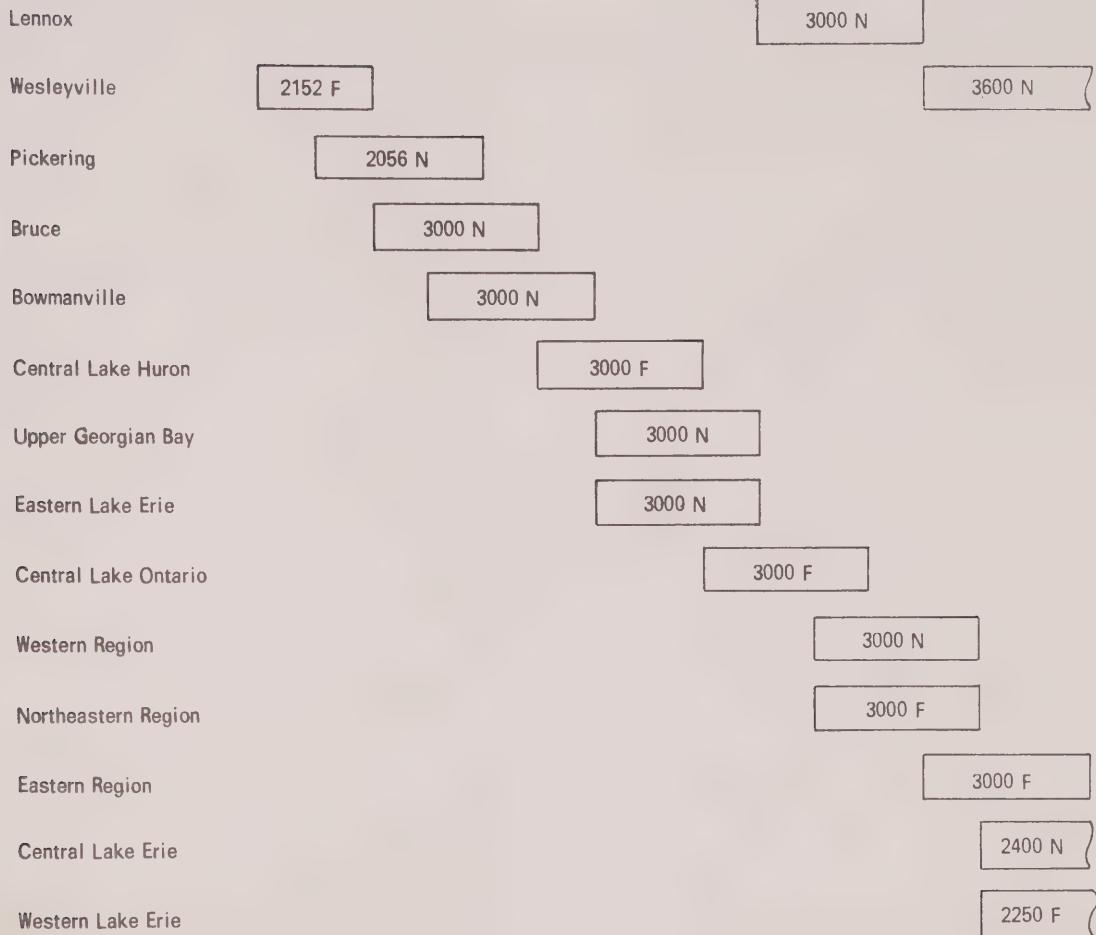
ONTARIO HYDRO SYSTEM PLANNING JAN 14 1974

FIGURE 1

DWG-13868 SP

79 80 81 82 83 84 85 86 87 88 89 90 91 92 93

year



79 80 81 82 83 84 85 86 87 88 89 90 91 92 93

year

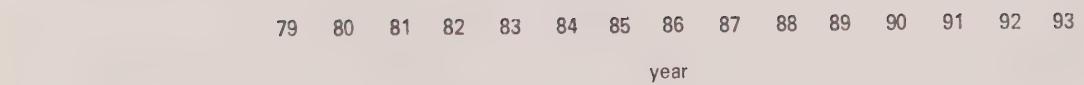
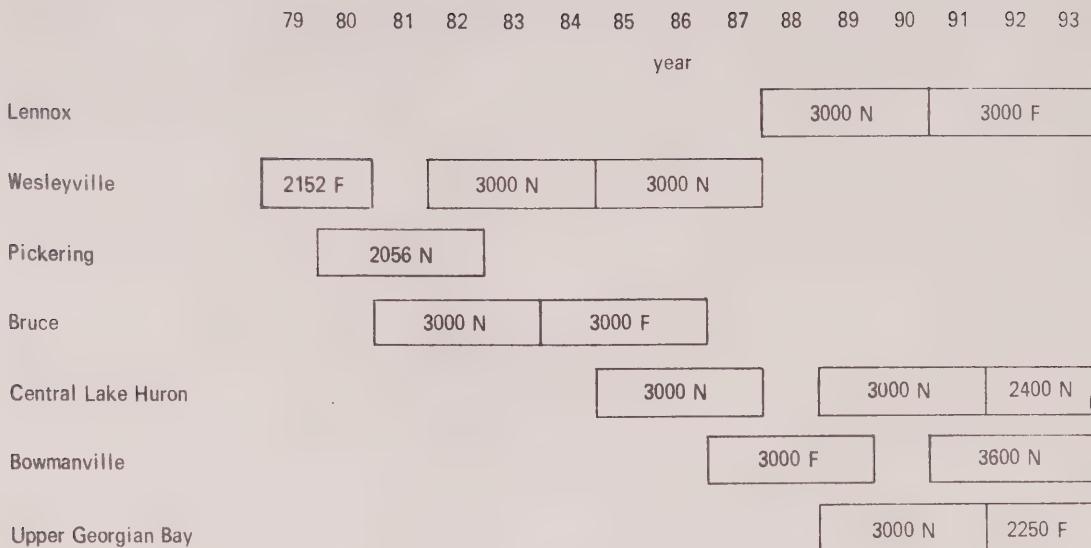
7% load growth

plant sizes in
megawatts

energy centres

N - nuclear
F - fossil

East System Tentative Generation Program Alternative A



7% load growth
energy centres

plant sizes in
megawatts
N - nuclear
F - fossil

East System Tentative Generation Program Alternative B

79 80 81 82 83 84 85 86 87 88 89 90 91 92 93

year

Lennox

Wesleyville

2152 F

Pickering

2056 N

Bruce

3000 N

Bowmanville

3000 N

Central Lake Huron

3000 F

Upper Georgian Bay

3000 N

Eastern Lake Erie

3000 N

Central Lake Ontario

3000 F

Eastern Region (A)

3000 N

Western Region

3000 N

Northeastern Region

3000 F

Toronto West

3600 N

Eastern Region (B)

3000 F

Central Lake Erie

2400 N

Western Lake Erie

2250 F

79 80 81 82 83 84 85 86 87 88 89 90 91 92 93

year

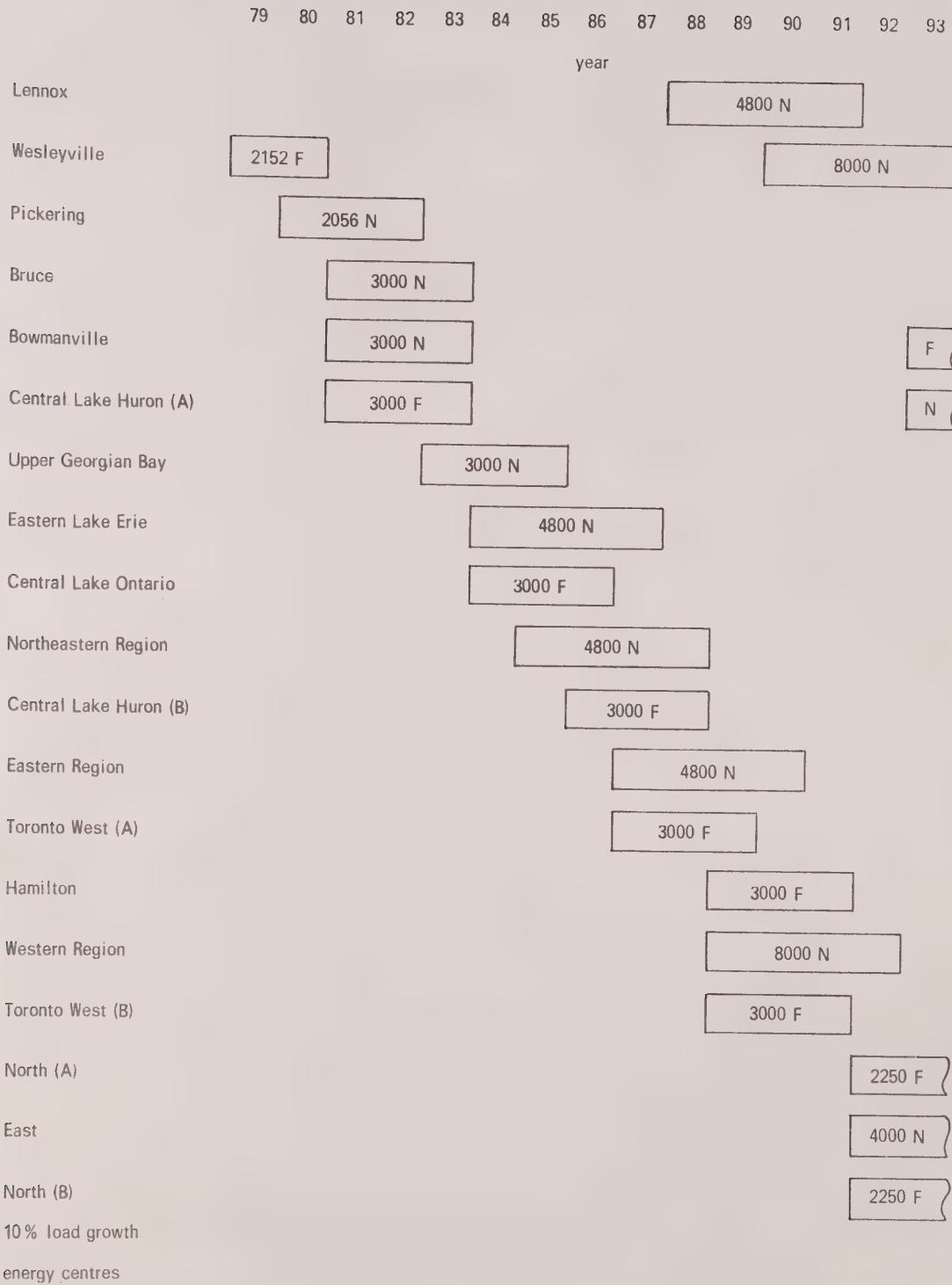
7% load growth

plant size in
megawatts

4-unit plants

N - nuclear
F - fossil

East System Tentative Generation Program Alternative C



East System Tentative Generation Program Alternative D

79 80 81 82 83 84 85 86 87 88 89 90 91 92 93

year

Lennox

3000 F

F

Wesleyville

2152 F

Pickering

2056 N

Bruce

3000 N

Bowmanville

3000 N

Central Lake Huron

3000 N

Upper Georgian Bay

3000 N

79 80 81 82 83 84 85 86 87 88 89 90 91 92 93

year

4 % load growth

plant size in
megawatts

energy centres

N - nuclear
F - fossil

East System Tentative Generation Program Alternative E

